File Copy 441
Do not Remove

RECENT ADVANCES IN ELECTRON-SPIN POLARIZATION MEASUREMENTS

Robert J. Celotta and Daniel T. Pierce

National Bureau of Standards
Washington, D. C. 20234

INTRODUCTION

The usefulness and importance of electron spectroscopy is well illustrated by the talks at this conference. It is, however, in some sense surprising how many measurements are made of the electron momentum while so few utilize the other available parameter, the electron polarization. This is due in part to the historically cumbersome and inefficient nature of electron polarization devices. Now that we have passed through a period of rapid technological advancement in sources and detectors of electron polarization and are also posing more detailed questions about the electron scattering process, the use of electron spin-polarization techniques is increasing rapidly. This paper will summarize the interactions that can be studied and the current state of the art in sources and detectors and offer illustrations of the types of experiments now being performed or planned.

SPIN-DEPENDENT INTERACTIONS

The two spin-dependent interactions[1] that are investigated are the spin-orbit and the exchange interaction. In the former, the spin dependence originates in the interaction between the incident electron spin and the motional magnetic field of the Coulomb core. It is most prominent for high-Z targets and large-angle scattering. It can cause dramatic polarization effects near cross-section minima. For high energies, ≈100 KeV, the scattering is from the nucleus and is accurately calculable, forming the basis for the Mott polarization analyzer.

The exchange interaction results from the Pauli exclusion principle and can be studied by preparing the incident beams in selected spin states and varying the relative spin orientations. It is largest at low energies and is usually relatively small when compared with the Coulomb interaction; excitation of a spin-forbidden transition would be an exception.

POLARIZATION SOURCES AND DETECTORS

There has been a rich history of processes developed to produce polarized electron beams.[1,2] A very substantial improvement in source capabilities occurred with the introduction of the BaAs photoemission source.[2,3] This source has been demonstrated to produce currents of hundreds of microamps of 40% polarized electrons with characteristics similar to conventional electron sources except that optical modulation of the electron polarization is possible. The fact that a GaAs polarized electron gun[3] can be used in place of a conventional gun in most applications with no loss in signal strength but allowing the measurement of spin-dependent quantities accounts for the almost universal acceptance of this technique.

Polarization detectors are still far from comparable with ordinary electron detectors, but some significant improvements have been made in the past few years. The standard for comparison is the Mott detector, where electrons are accelerated to ≈100 KeV and backscattered from a thin gold foil. Between 10^{-3} and 10^{-5} of the incident beam is collected by two large-angle detectors placed at ±120° to the incident direction. If the beam were polarized normal to the scattering plane, these detectors would register different count rates. This difference is a linear function of the beam polarization and the Sherman function[1] of the detector, $S \approx 0.2$. The figure of merit[1] for polarization detectors is $S\ I/I_0$ where I/I_0 is the fraction of incident electrons collected.

Low-energy electron diffraction[4] offers an alternative to Mott detection. Here the spin-orbit interaction is still the basis for the spin-dependent scattering, but the scattering takes place at ≈100 eV and the periodic arrangement of the atoms in the single crystal target gives rise to electron diffraction which focuses the backscattered electrons into conveniently measured spots. Such detectors offer significant advantages because of their size and energy range and are as efficient as the best Mott detectors.

A very new, exceedingly simple polarization detector is based on the spin-dependent absorption[4] of electron by a metal target. As the energy of electrons incident on a metal is increased, an energy is reached where enough secondary electrons are produced so that the total current collected by the target is zero. If the target can cause spin-dependent scattering, due to either the spin-orbie or the exchange interaction, then the energy at which a current balance occurs will be different for two incident spin states. This detector[5] is very simple, consisting of no more than a gold surface at an inclined angle, is highly efficient and is capable of operating in a mode where only electrons of one spin are detected.

EXPERIMENTS

A wide variety of experimental investigations is currently underway using these new technologies. The emphasis is on using state selection or coincidence techniques to permit the determination of quantum amplitudes and phases rather than cross sections. Examples of recent measurements include studies of spin-orbit effects in Xe elastic scattering,[6] interference between exchange and spin-orbit in Hg excitation,[7] the asymmetry in near threshold ionization of Li,[8] and spin exchange in e^--H scattering.[9] Future experiments include complete measurements of the direct and exchange amplitudes and their phase difference for elastic e^--alkali scattering, study of exchange effects in inelastic scattering and scattering from excited states, and the extension of electron-photon coincidence techniques to include spin polarization.

To date, most electron polarization measurements have been made on surfaces or atoms. Some work has been done on electron-molecule scattering[1] with the emphasis on using the spin-dependent effects caused by a high-Z atom in an otherwise low-Z molecule as an indicator of where the scattering occurred. More recently polarization effects in electron scattering from chiral molecules have been studied.[10] Future electron-molecule studies can be envisaged which include using polarization techniques to isolate those excitations which proceed through spin exchange.

REFERENCES

1. J. Kessler. Polarized Electrons, Springer-Verlag, New York, 1976.
2. R. J. Celotta and D. T. Pierce. Adv. Atom. Molec. Phys. 16, 102 (1980).
3. D. T. Pierce, R. J. Celotta, G.-C. Wang, W. N. Unertl, A. Galejs, C. E. Juyatt, and S. R. Mielcsarek. Rev. Sci. Instrum. 51, 478 (1980).
4. D. T. Pierce and R. J. Celotta. Adv. Electron. Electron. Phys. 56, 219 (1981).
5. D. T. Pierce, S. M. Girvin, J. Unguris, and R. J. Celotta. Rev. Sci. Instrum. 52, 1437 (1981).

6. W. Wübker, R. Möllenkamp, and J. Kessler. Phys. Rev. Lett. 49, 272 (1982).
7. K. Bartschat. G. F. Hanne, A. Wolcke, and J. Kessler. Phys. Rev. Lett. 47, 997 (1981).
8. G. Baum, E. Kisker, W. Raith, W. Schröder, U. Sillman, and D. Zenses. J. Phys. B14, 4377 (1981).
9. G. D. Fletcher, M. J. Alguard, T. J. Gay. V. W. Hughes, C. W. Tu, P. F. Wainwright, M. S. Lubell, W. Raith, and F. C. Tang. Phys. Rev. Lett. 48, 1671 (1982).
10. M. J. Beerlage, P. S. Farago, and M. J. Van der Weil. J. Phys. B14, 3245 (1981).